

Search for New Physics at the Tevatron

Símona Rollí Tufts University

(on behalf of the CDF and DO Collaborations)



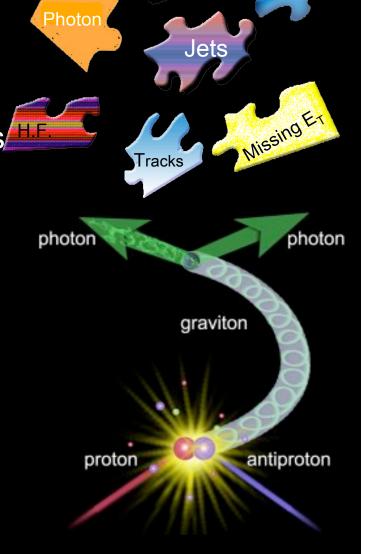
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Muons

Outline of the talk

TeVatron status

- Physics Processes and their signatures
 - from simple objects to complex final states
 - leptons-only final states (and isolated tracks)
 - ... + Missing Energy and Photons
 - ... + Jets and heavy flavors
 - Specific model testing and global searches
- Final remarks and conclusions



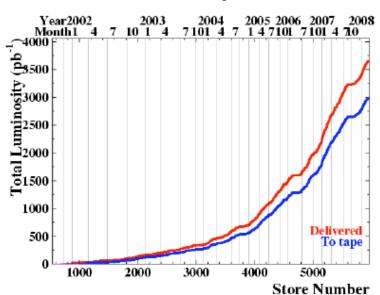


TeVatron Status

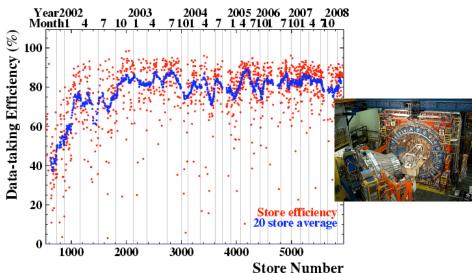
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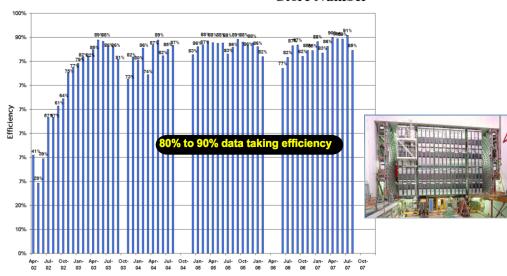
The TeVatron is doing very well!

Luminosity Profile



Delivered Lumi. > 3.6 fb⁻¹ Good for analysis ~ 3. fb⁻¹







Signatures and Physics Objects

We study physics processes organizing them by their signature

Leptons-only final states

- e/μ identification well understood
- $\bullet \tau$ id a little more complex
- Straightforward and highly efficient approach to search for anomalies
- + Missing Energy and Photons
 - Wealth of models and exotic processes
 - Need accurate understanding of detector effects
- •... + Jets and heavy flavors
 - More complex signatures
 - Maintaining high S/√B

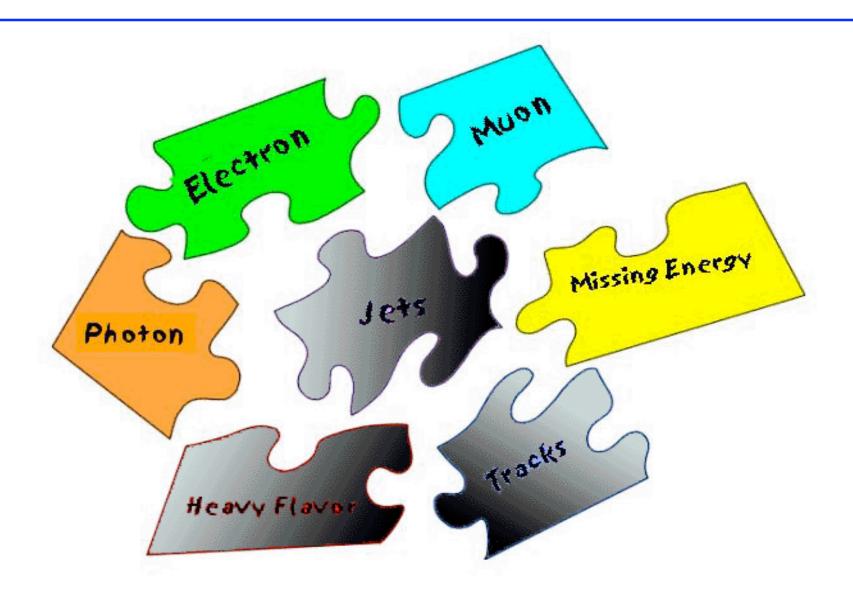
When a <u>signature-based</u> approach is advocated, results are generally interpreted in terms of specific models (typical case dilepton searches, MET + jets)

When the analysis is <u>model driven</u> and results are presented as testing of a specific model, there is always a check on control regions, defined in terms of the process signature (blind analyses)

The two approaches are usually pursued in a balanced and complementary way



Leptons, Photons and MET





Searches in dilepton final states

Old-fashioned mass bump hunt...

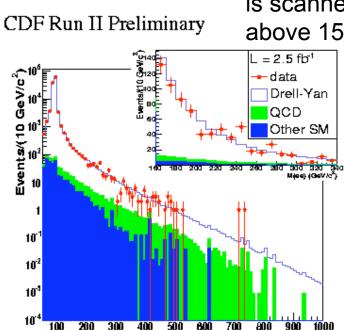
- -Z production and decay into ee/μμ precisely measured
- -Lepton ID/Reco and Trigger efficiencies high and very well understood
- -Background low and easily determined (QCD fakes)

M(ee) (GeV/c²)

-Clean events

is scanned in search for excesses in above 150 GeV/c²

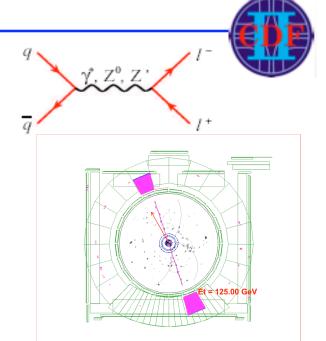
At CDF the dielectron mass spectrum



The most significant region of excess for an e⁺e⁻ invariant mass window of 240 GeV/c²

3.8 standard deviations above the SM prediction Excess dependent on ID variables cuts...

The probability of observing a background fluctuation with significance equal to or greater than 3.8 anywhere in the mass range of 150-1,000 GeV/ c^2 is about 0.6%, corresponding to a 2.5 σ significance.





Testing different models

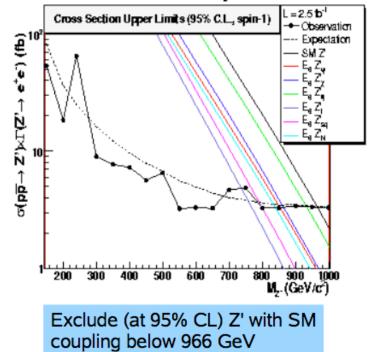
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Once the data spectrum is well understood in terms of SM background, from MC, the acceptances for resonant states for different spin particles are derived (Z', RS Graviton) and the expected number of BSM events is calculated.

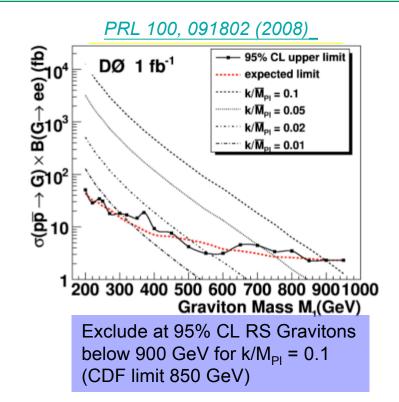
In the absence of an excess of data, 95% CL limits on production cross-sections and

mass of the particles are set.

CDF Run II Preliminary



μμ channel analyzed with the same strategy. Update to 2fb⁻¹ in progress





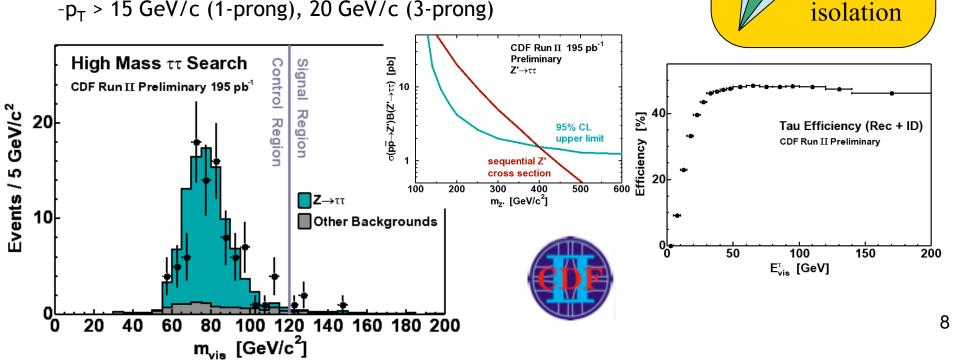
Tau final states

τcone

 $\tau_h ID$

Ditaus final states are selected where

- •One tau decays leptonically: e/μ (CDF) μ (DØ) (plus v's)
- • $p_T > 10 \text{ GeV/c (CDF)}, p_T > 15 \text{ GeV/c (DØ)}$
- -Other tau hadronic (and v_{τ})
 - -One or three tracks ($\Sigma q_{trk} = \pm 1$), opposite to lepton
 - -CDF: isolation 30°, shrinking τ cone (10° \rightarrow 3°)
 - -DØ: three types (π^{\pm} , $\pi^{\pm}\pi^{0}$, 3-prong), NN score
 - •No electron veto (allows eμ)
 - $-p_{T} > 15 \text{ GeV/c (1-prong)}, 20 \text{ GeV/c (3-prong)}$

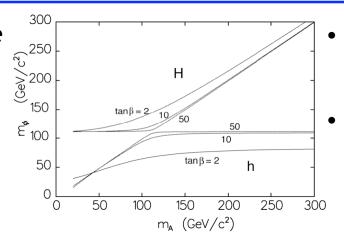




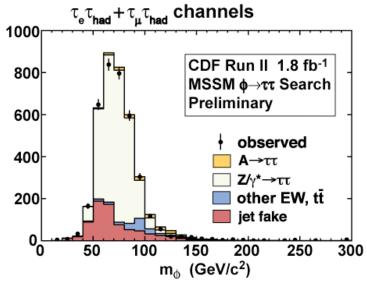
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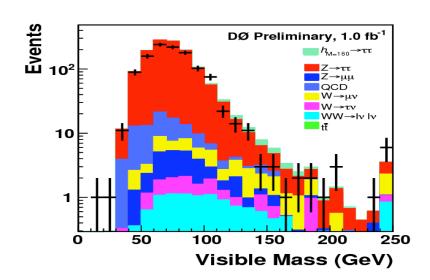
MSSM Higgs $\phi \rightarrow \tau \tau$

- In the MSSM framework the Higgs neutral sector simplifies at high tanβ
- A and h/H become degenerate
- Other scalar SM-like, low cross section



- Only need to search for a single mass peak (ϕ)
- For the A and its twin h/H, at high tan β decays into bb (90%) and $\tau\tau$ (10%) dominate



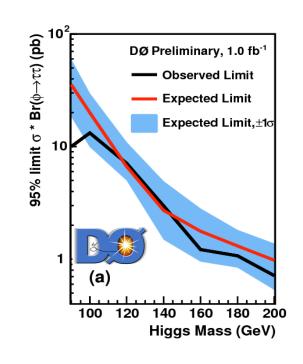


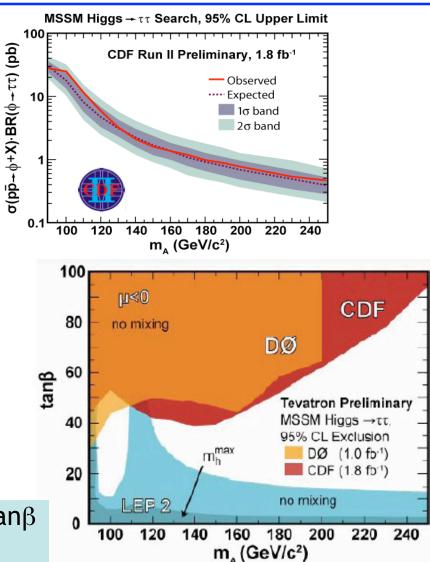
• No excess in $e/\mu + \tau_{had}$ channel (slight excess for CDF in 2007)



$\phi \rightarrow \tau \tau$ Results



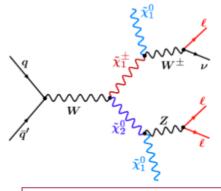




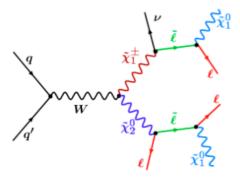
Interpret σ x BR limits as limits on tan β vs m in MSSM benchmark scenarios

Multileptons final states: SUSY in Trileptons

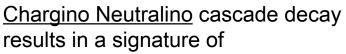




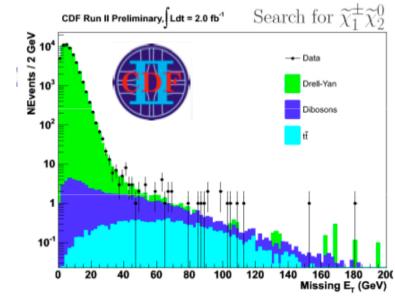
Decays through W/Z favorable for heavy sleptons, but BR to leptons low



Decays through sleptons guarantee final leptons, but also preference to $\widetilde{\tau} \to \tau$



(3 leptons or 2 leptons + track) and MET

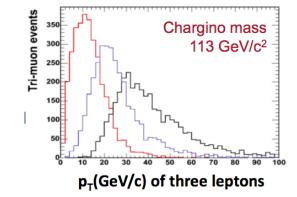


Selection (signal region):

- p_τ (15,10/5,5) GeV/c
- MET>20 GeV (DY and QCD rejection)
- $-N_{iets} \le 1$ and $H_T < 80$ (top rejection)
- Z-mass veto (DY rejection)
- Dilepton Mass above 20 GeV/c² (QCD and resonance rejection)
- Trilepton backgrounds:
 - DY+fake, Z+γ, diboson

Control regions in MET vs Mee phase-space

 Signal region is investigated only after validating backgrounds in control regions (a blind analysis)



Similar cuts at D0



SUSY in Trileptons

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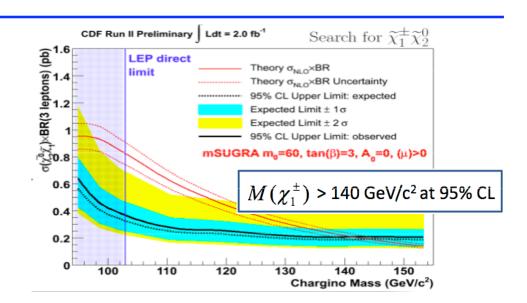
- Signal region is investigated only after validating backgrounds in control regions (a blind analysis)
- Good agreement with SM background

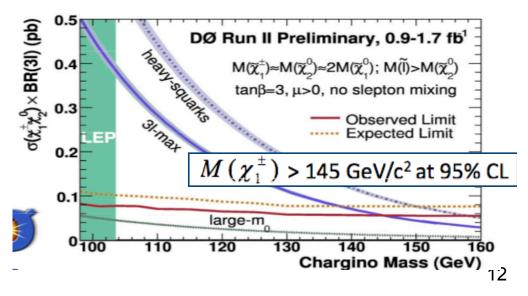
CDF Run II Preliminary, $\mathcal{L} = 2.0 \text{ fb}^{-1}$

Analysis	Backg.	Signal	DATA
Trilepton	0.9 ± 0.1	4.5 ± 0.6	1
Dilepton+Track	6.9 ± 0.9	5.5 ± 1.1	6

DØ Run II Preliminary,

Analysis	L	Backg.	Signal	DATA
Amanyono	(fb)	Duelig.	J.B.I.u.	
ee+€	0.6	1.0 ± 0.3	0.5 - 0.2	0
μμ+θ	1	0.3+0.7	0.5 – 2.5	2
еµ+€	1	0.9+0.4	1-4	0
ee+€	1.1	0.8 ± 0.7	1.7 – 4.7	0
$\mu^{\pm}\mu^{\pm}$	0.9	1.1 ± 0.4	0.6 – 3.7	1





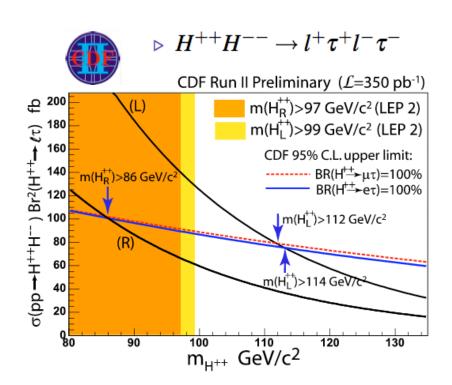
Multi leptons final states: **Doubly Charged Higgs**

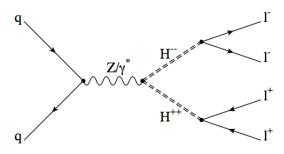


4 leptons final state

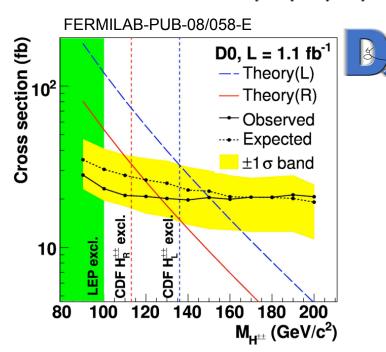
$$\vdash H^{++}H^{--} \to l^+l^+l^-l^-$$

$$\triangleright H^{++}H^{--} \to \mu^{\pm}\mu^{\pm}e^{\mp}e^{\mp}$$





$$\vdash H^{++}H^{--} \to \mu^{+}\mu^{+}\mu^{-}\mu^{-}$$



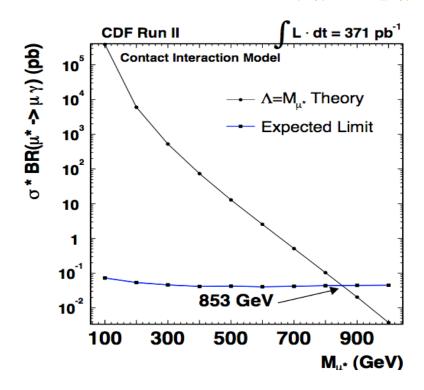
Lepton+γ final states: Excited leptons



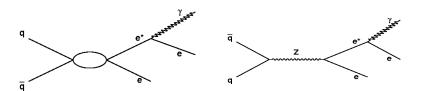
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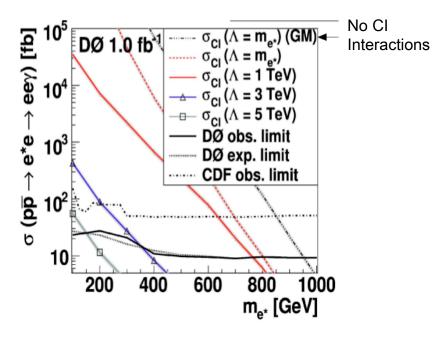
Observation of excited states of quarks and leptons might confirm the hypothesis that they are not elementary particles, but composite states

Select events with eey ($\mu\mu\gamma$) in the final state and look for resonance in M($e\gamma$) or M($\mu\gamma$)



At Tevatron, e^*/μ^* can be produced via contact interactions or gauge mediated interactions



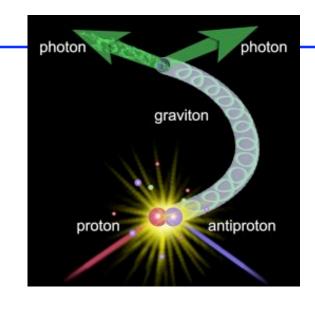


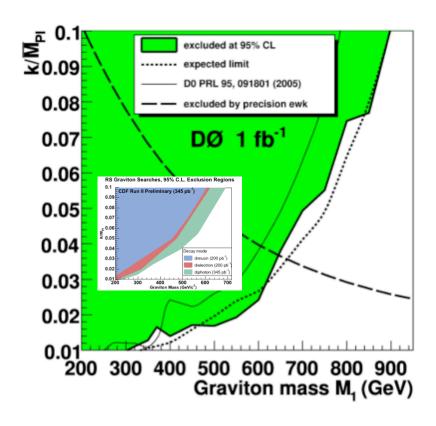


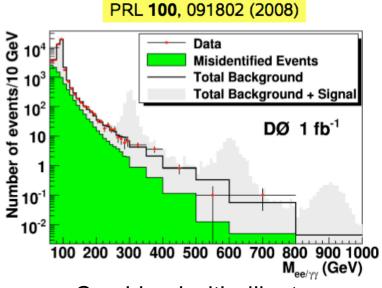
Diphotons:LED

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The search for new particles decaying to diphotons uses the RS graviton model to express sensitivity to Kaluza-Klein graviton resonances (spin 2 resonance)







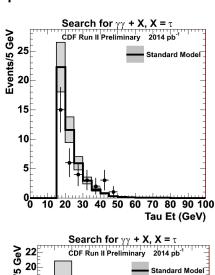


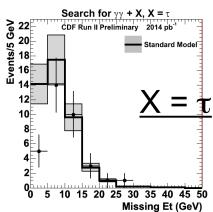
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Diphoton+X

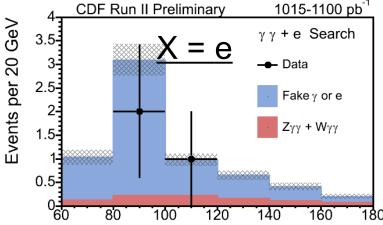
Nominal high E_T object identification and kinematic selections are used.

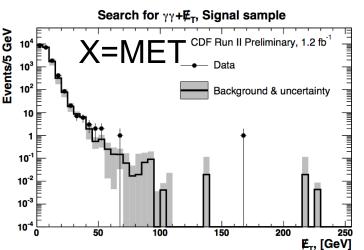
The observed event counts is reported as well as SM prediction for various kinematic distributions

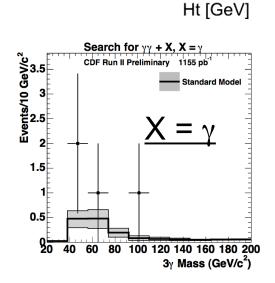












Good agreement between data and SM predictions



data

 $W/Z+\gamma\gamma$

electron mis-ID jet mis-ID

SM + signal A=75 TeV

SM + signal A=90 TeV

γγ

diphoton + MET: GMSB SUSY

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GMSB scenario NLSP = $\chi^0_1 \rightarrow \gamma \widetilde{G}$

$$p\overline{p} \rightarrow (X \rightarrow) \chi^0_1 \chi^0_1 \qquad 2 \gamma + E_T$$

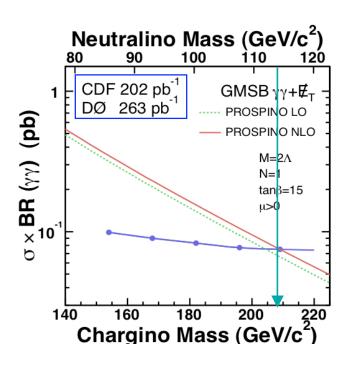
DØ 1.1 fb⁻¹

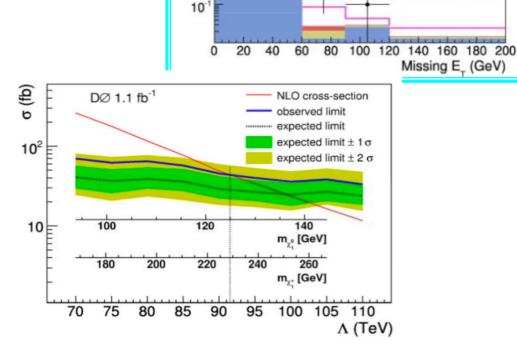
GeV

3

Events per

10

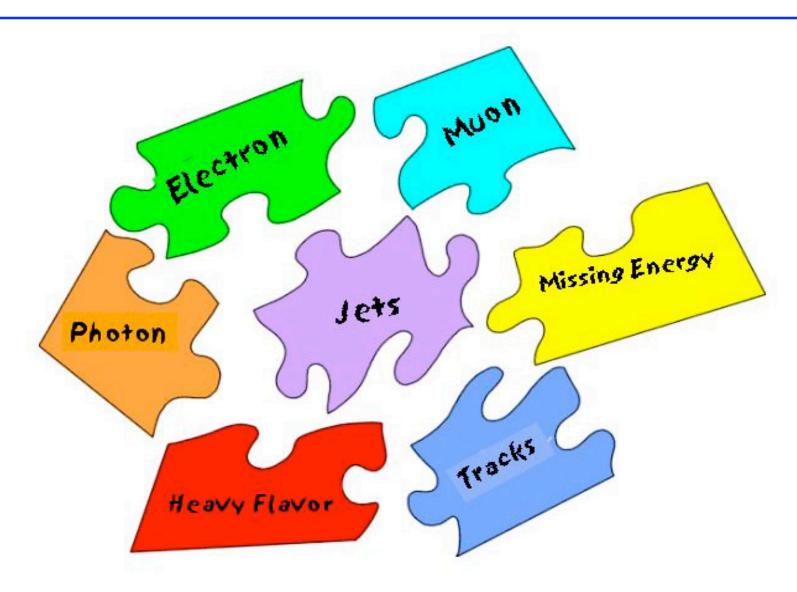






Adding jets and flavor tagging







Jets and Heavy Flavor

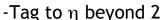
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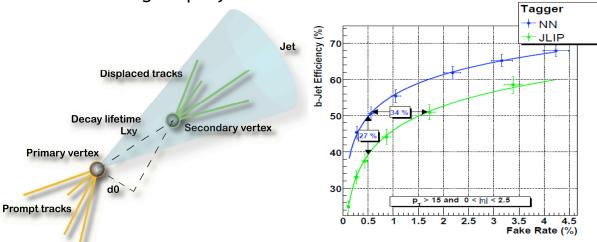
Hadronic jets are reconstructed using several algorithms: Cone, Midpoint, KT etc..

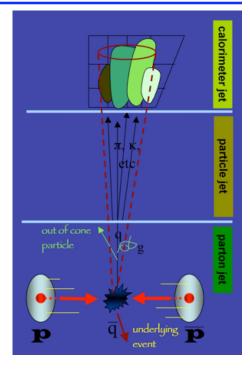
Measured jet energies are corrected to scale them back to the final state particle level jet . Additionally there are corrections to associate the measured jet energy to the parent parton energy, so that direct comparison to the theory can be made. Currently the jet energy scale is the major source of uncertainty in the measurement of the top quark mass and inclusive jet cross section

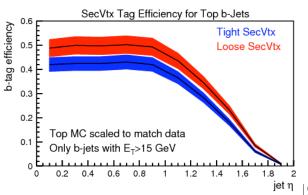
B-jet identification is implemented via:

- -displaced vertices with L_{xy}/σ cut (CDF)
- -Vertex mass separation (CDF)
- -combining vertex properties and displaced track info with NN (D0)









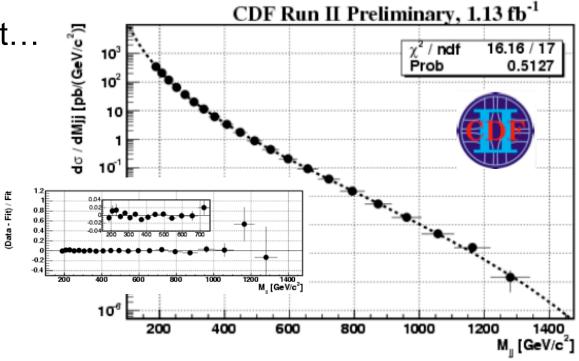


Dijets final state: mass bumps

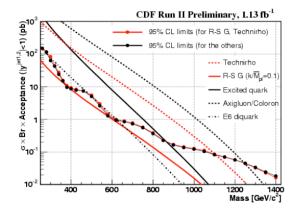
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Another mass bump hunt...

- Choose events with two highp_⊤ jets with rapidity less than
 1.0. Look for an excess in the dijet mass spectrum for masses above 180 GeV
- Possible signals include excited quarks, W', Z', and Randall-Sundrum gravitons
- Find functional form of dijet spectrum in pythia and herwig, fit to data. Look for "bumps" in the data minus fit plot



- No significant resonant structure is observed, so limits are set on various models
- Excludes (at 95% CL) excited quarks from 260-870 GeV, W' from 280-840 GeV, and Z' from 320-740 GeV

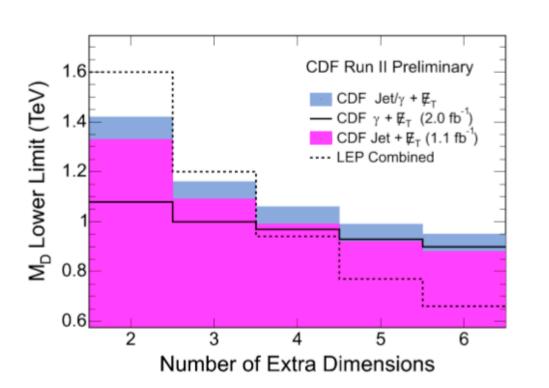


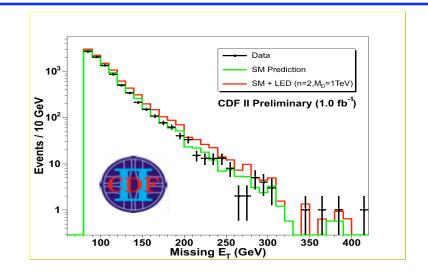


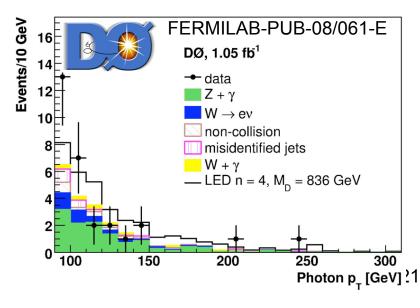
Single jet + MET: LED

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A Kaluza-Klein graviton is produced in association with a jet (or photon). The graviton escapes detection, leaving a monojet (monophoton) signature in the detector



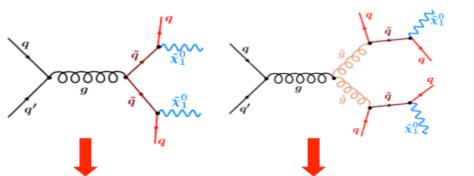




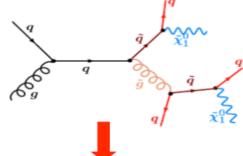
MET + jets: SUSY squarks and gluinos



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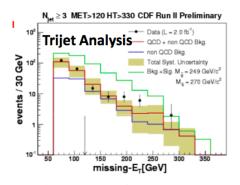


Result: 2 jets and MET Result: 4 jets and MET Result: 4 jets and MET



Result: 3 jets and MET

- Although the production is strong, the analyses are challenging due to QCD-multijet and W/Z+jet backgrounds
 - **Solution:** break-down analyses in jet-multiplicity bins and optimize separately (using MET and HT← Sum of jet E_{τ})



D0,PLB 660, 449 (2008), \mathcal{L} =2.1fb⁻¹

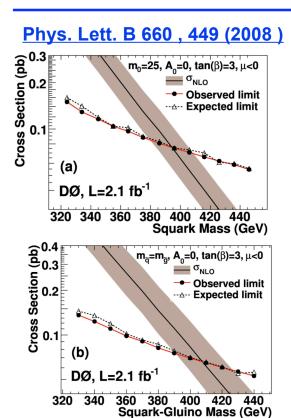
CDF Run II Preliminary, $\mathcal{L} = 2.0 \text{ fb}^{-1}$

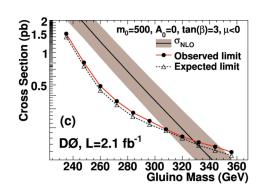
Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA	Analysis	HT cut (GeV)		Jet Et (GeV)	Bckg.	DATA
Dijet	325	225	35,35	11 ± 1 +3/-2	11	Dijet	330	180	165,100	16 ± 5	18
Trijet	375	175	35,35,35	11 ± 1 +3/-2	9	Trijet	330	120	140,100,25	37± 12	38
4-jet	400	100	35,35,35,20	18 ± 1 +6/-3	20	4-jet	280	90	95,55,55,25	48 ± 17	45

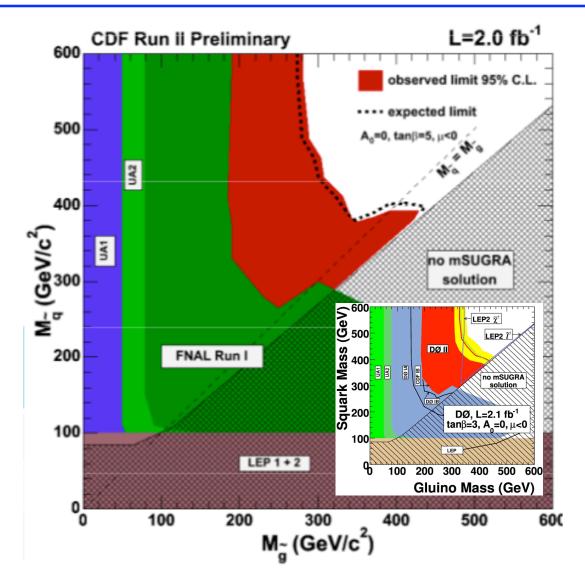


SUSY in MET + jets

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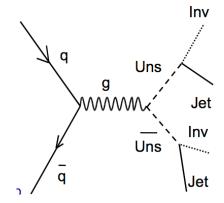






Jets+MET final state: Leptoquarks





The analysis is a counting experiment examining two different kinematic regions (each region being more sensitive to different models).

Cuts are not optimized for a specific model.

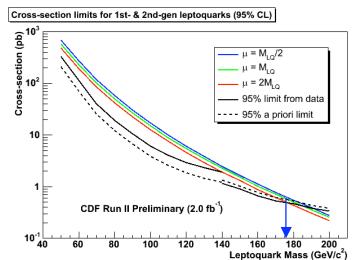
Main backgrounds:

- $-Z \rightarrow v v + jets$ (irreducible background)
- $-W \rightarrow I \nu$ + jets (with charged lepton lost)
- -Residual QCD and non-collision backgrounds.

Data driven prediction

CDF Run II Preliminary, 2fb⁻¹

Background	125/80	225/100
Z → νν	777 ± 49	71 ± 12
$W \rightarrow \tau \nu$	669 ± 42	50 ± 8
$\mathbf{W} \rightarrow \mu \nu$	399 ± 25	33 ± 5
W → ev	256 ± 16	14 ± 2
Z → II	29 ± 4	2 ± 0
QCD	49 ± 30	9 ± 9
γ + jets	55 ± 13	5 ± 3
top	74 ± 9	11 ± 2
non-collision	4 ± 4	1 ± 1
Total	2312 ± 140	196 ± 29
Observed	2506	186

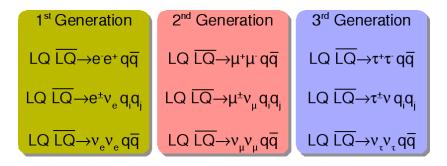


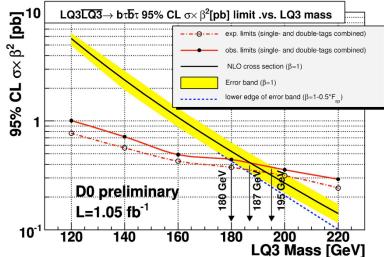
MET

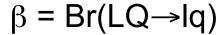


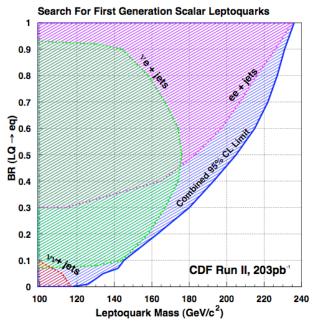
Other LeptoQuarks Results

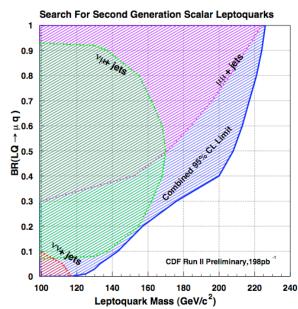
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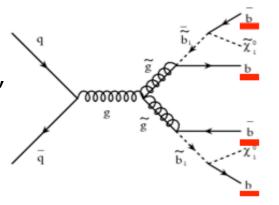




HF final states: sbottom from gluinos

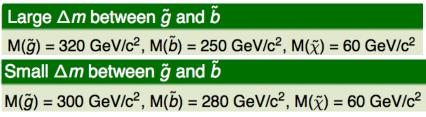


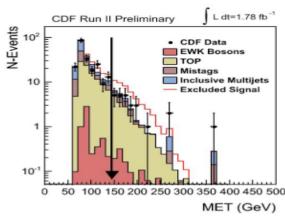
If the sbottom is significantly lighter than the other squarks, the two body decay of gluino into bottom/sbottom is kinematically allowed

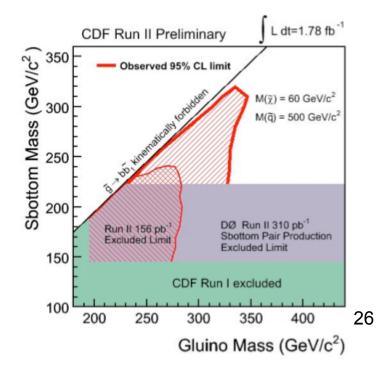


The sbottom decays into a bottom and LSP, giving rise to a final state with <u>4</u> <u>b-jets and missing energy</u>

The analysis is optimized for 2 points in the SUSY parameter space:



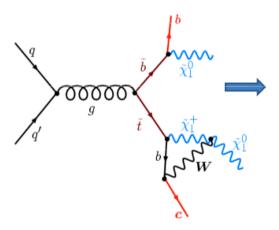






Stop searches



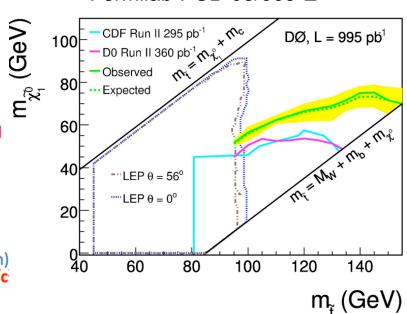


Light stop and sbottom production and decay

Stops to charm

- Exactly 2 jets (reduction of QCD)
- Jet pt cuts (20,40 GeV/c) and angular separation of jets (reduces QCD and W+jets)
- Angle between jets and met (reduction of QCD)
- Flavor tagging using Neural Network (impact parameter, secondary vertex information)

Exclusion: stop mass <149 GeV/c neutralino mass of 63 GeV/c²

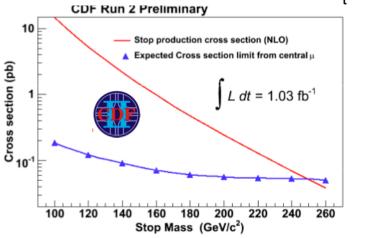


Fermilab-PUB-08/063-E

Other option is that stop does not decay in the detector (CHAMP)

- Slow particle signature: slowly-moving highly-ionizing highly-penetrating particle
 - Will look like muon with possible calorimetry energy deposition
 - Particle mass is measured using Time of Flight

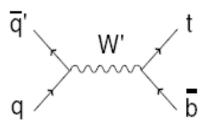
Stable stop mass > 250 GeV/c² at 95% CL



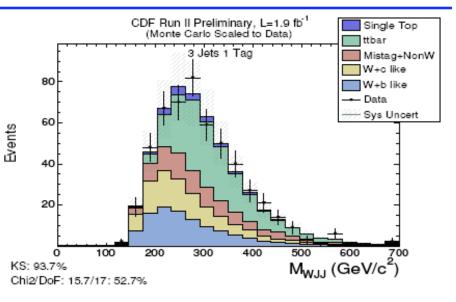
Heavy flavor final states: W'→ tb



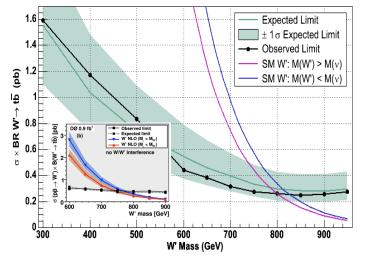
Simona Rolli - Tufts University



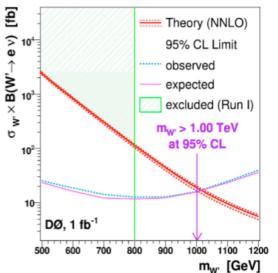
Search for resonant tb(+cc)
pair production
In W+2 jets and +3 jets
channels (semileptonic W),
look for unexpected structure
in M(Wjj)



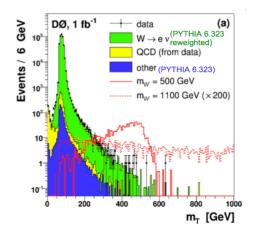
95% C.L. Observed Limit - CDF Run II Preliminary: 1.9 fb⁻¹



Extra W gauge boson decaying into ev



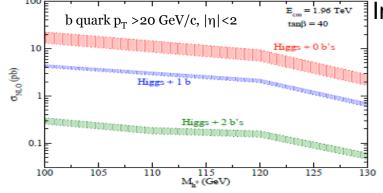
Phys. Rev. Lett. 100, 031804 (2008)



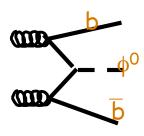


HF final states: φ→bb



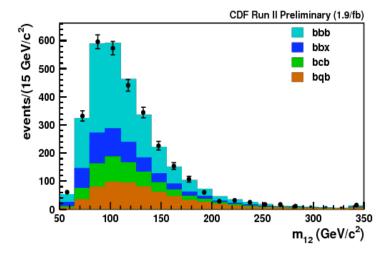


Inclusive $H \rightarrow b\underline{b}$ is too hard due to QCD background

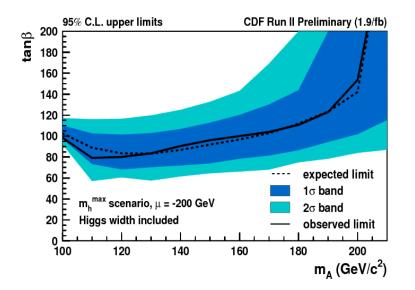


Require one additional bottom quark jet besides the two from Higgs decay

"3b" channel best compromise between signal and background rates



Search in mass of two lead jets m₁₂ No excess observed



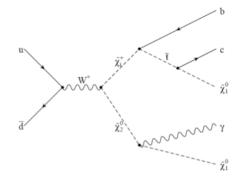
More complex signatures: γ+b+jets+MET



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A handful of exotic processes would give rise to a final state signature comprising γ+b+jets+MET Many anomalies could be reduced to detector mis-measurements.



Low energy SUSY with radiative decay of the neutralino

Selection:

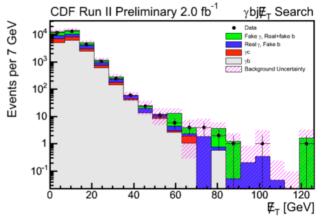
One high E_T photon

≥ 2 jets

≥ 1 tagged jet Large MET (> 25 GeV) Topological cuts Main background is dominated by fake γ or b. Calculated using MC or data

CDF Run II Preliminary, 2 fb⁻¹

Source	Number
γb	291 ± 7 (stat.) ± 50 (syst.)
γс	92 ± 25 (stat.) ± 45 (syst.)
Fake b, real γ	141 ± 6 (stat.) ± 30 (syst.)
Fake γ	113 ± 49 (stat.) ± 54 (syst.)
Total	637 ± 54 (stat.) ± 128 (syst.)
Data	617





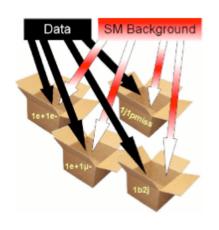
Global Searches

The goal is to perform a model-independent global search of high P_T data:

- -study bulk features of high P_⊤ data;
- -search for resonances invariant mass distributions
- -search for significant excesses at high sum-p_T

b T T

Physics objects are categorized and events selected and partitioned into ~400 exclusive final states



The whole high P_T region is monitored at once

Pythia and MadEvent are used to implement the SM theoretical prediction (CdfSim emulates the detector response)

Many correction factors are used to obtain the *true* SM predictions (shouldn't a global search work globally?)

theory k-factors etc experimental efficiencies and Scale Factors, fake rates etc

Currently observed discrepancies are explained in terms of incorrect MC modeling



Many exciting results are continuously produced at the Tevatron!

We are still the place of interest and will be for a few more years!

The search for physics beyond the SM is carried on through a careful analysis of various final states using model driven as well as signature based approaches.

A bump can be around the corner before the LHC turns on....

